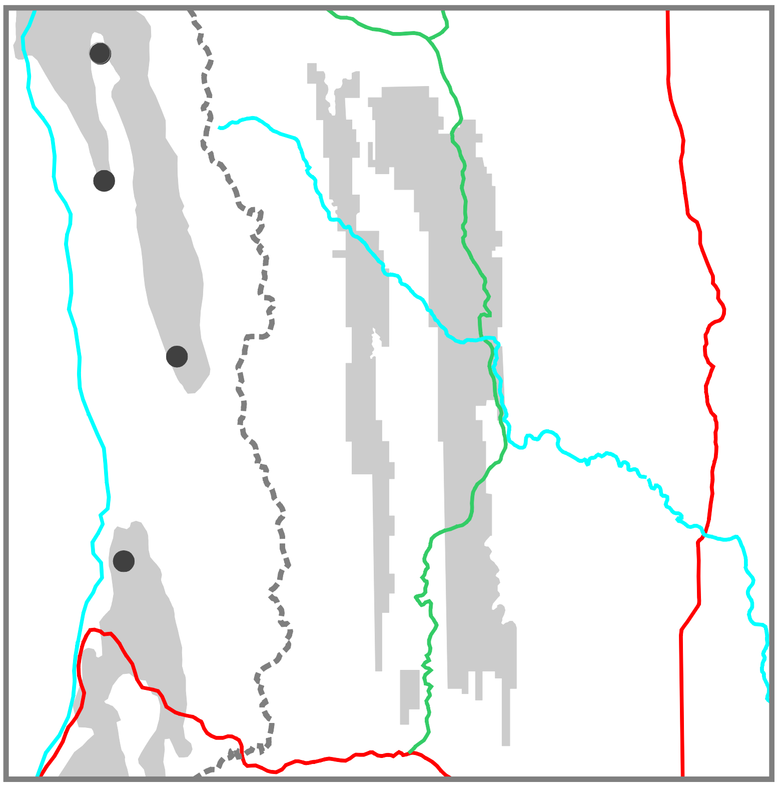
SUBMISSION TO THE COAL POLICY COMMITTEE

The Price of Coal

A Geological Perspective



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2021-06-29

Classification: Protected A

Introduction

Dear Committee Members:

In the coming weeks, you will be reviewing many submissions about the pros and cons of introducing open pit mining into the once-protected Mist Mountain Formation of Alberta's Rocky Mountains, and preparing a summary of relevant information to forward, along with your own recommendations, to our provincial government.

My submission focuses on one subject, the concern felt by many scientists that such a development may pose a serious threat in the Oldman River Watershed, and beyond. It summarizes scientific studies which give information about some of the risks endemic to deep-slope mining in this formation, a major one being the contamination of water supplies by the release of selenium. For my qualifications for assessing available data, please see the brief bio at the bottom of this page.

This submission draws on the experience of mining in a situation that is geologically identical to that of the mines under consideration. In our comparison mines, neither scientific ingenuity nor very heavy financial outlay has been able to deal with the selenium problem.

I was surprised to learn that the Grassy Mountain project, now rejected, had been specifically carved out of the terms of reference for your committee, since it is in the same Mist Mountain Formation as the sites you have been asked to consider, and since a major assessment has been made of the risks of introducing strip mining there. That assessment was made by Dr. A. Dennis Lemly, an internationally recognized authority on selenium pollution. Because I feel that it is important that your committee should have access to the information contained in his peer-reviewed report, I have cited it in several places in my own submission, where it is referred to either by the author's name, or as 'the Lemly Report'. In addition, you will find Dr. Lemly's complete report attached separately.

Respectfully submitted,

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Part One – Mining for coal

1. If things go wrong

While small amounts of selenium are essential for health in some species, too much selenium – whether ingested through drinking water or from accumulation in the food chain – can have devastating effects. In water birds, it may result in reproductive failure: eggs that fail to hatch. In fish, it has caused gross deformities: pug noses, missing gill covers, spines that are shaped like question marks…and sometimes even mass die-outs.

In human beings, reported results include nervous system damage, chronic nausea, and the loss of hair, fingernails, and toenails. Grazing animals may be similarly affected. Marco Polo, visiting China at the end of the thirteenth century, described seeing horses that had lost their hooves and shed hair from their manes and tails from being taken to a certain mountain area, a condition that veterinarians of more recent times have diagnosed as being due to selenium poisoning.

Clearly, these outcomes are not acceptable to either the supporters of mining or its opponents. Both, one would assume, would regard selenium release as an evil that must be controlled. The question is whether this aim is merely difficult to achieve, or absolutely impossible in the given environment.

2. Mining Practices – The problems of waste

Strip mining on mountain slopes presents risks that are different in kind from those we are familiar with in either the deep pit mining that was once practiced in the Crowsnest, or the strip mining that is now practiced in various parts of the province. One of the largest open pit operations in the world is in Alberta's Athabasca oil sands, but there, the terrain is horizontal, and abandoned pits can be used to dispose of waste rock.

Strip mining in the Mist Mountain Formation, where the proposed mines would be located, poses different challenges. Coal seams there are steeply sloped, which means that the rock faces of hillsides must be broken up and removed to get at the coal. For every tonne of coal removed, it is necessary to remove nearly six tonnes of waste rock. Then a site must be found to store this debris.

If suitable terrain is available, the waste rock may be stored on the same hillside as the mine, in which case it is known as 'hillside fill'. If this is not an option, the waste must be dumped into some nearby valley, where it is called 'cross-valley fill'.

But whatever you call them, these disarticulated mountains of waste rock constitute a major problem. And they grow in size year by year. Statistics show that in a single year, five mines in British Columbia's Elk River Valley – which are virtually identical to the ones proposed for Alberta – produced 24 million tonnes of coal and 140 million tonnes of waste rock (Lussier et al., 2003). That is, let me stress, the result of one year's mining only.

3. Why a rock pile is so worrying

Whatever substances the rock of any formation may contain, they are pretty well protected from release as long as the mountain is intact. However, once the rock has been broken up, as it is in surface mining, that natural protection is gone forever. Thousands of tonnes of rock and rubble – with many millions of facets exposed – lie unprotected, and soon begin to interact chemically with air and rain water. Once it has begun, there is no way of stopping the oxidation process. It will go on for as long as there is – in the case of mining in this formation – any selenium left in the rock.

Rain and snow-melt pass through the rubble, picking up the released chemicals, and carrying them in rivulets and streams to rivers in the watershed, and for many miles beyond its borders.

4. A problem called pyrite

The rocks of the Mist Mountain Formation contain troublesome amounts of pyrite (iron sulphide), a substance that is also known as *fool's gold*. But if *fool's gold* sounds almost like a joke, it is no laughing matter when exposed to weather. As pyrite breaks down, it releases selenium, and as the rock piles grow with time, so too does the amount of selenium released. There is no way to control or contain this process. And because the selenium is carried from the site by water, it is able to enter the food chain.

This process goes on for a very long time. A team of scientists headed by Jim Hendry (University of Saskatchewan) measured the selenium-bearing water draining from a waste dump in the Elk River Valley and calculated that – though thirty years had elapsed since the shattered rock was deposited – a mere twenty percent of its selenium had been leached out (Hendry et al., 2015). At this rate, it would take another 120 years – longer than any one of us alive today will be on this earth – before that rock pile will cease to pollute. That particular waste dump represents only a very small fraction (4.3%) of the total waste rock in the Elk River Valley. This allows us to calculate that over the lifetime of *all* the dumps in the Elk River Valley about 2470 metric tonnes of selenium will enter the environment.

5. Our coalfield's twin

We have already mentioned the Elk River Valley mines in British Columbia. They are located in the same Mist Mountain Formation as the proposed Alberta mines, which tells us that the difficulties that have arisen there will also arise here.

Can we be sure of that? Well, yes, we can, and for reasons that go back some 145 million years. At that time, the territory where the two coalfields are now located was part of a great swamp at the side of an ocean that stretched all the way down to the Gulf of Mexico. There were a few puny hills west of the swamp, but no mountains. As time went on, a large coalfield developed – *one* coalfield – until the Rocky Mountains rose and divided it in two (see Figure 1). The Alberta and B.C. coal fields today are like twins brought up in different households: separated by circumstance, but still with the same DNA.

There has been strip mining on the B.C. side of the border for forty years, using methods similar to those planned for Alberta, and this fact is particularly useful to us in predicting the problems that will arise, should mining go ahead on our side.

Some problems that have arisen in B.C.—serious problems—have proven to be insoluble, as will be shown in the next sections of this submission.

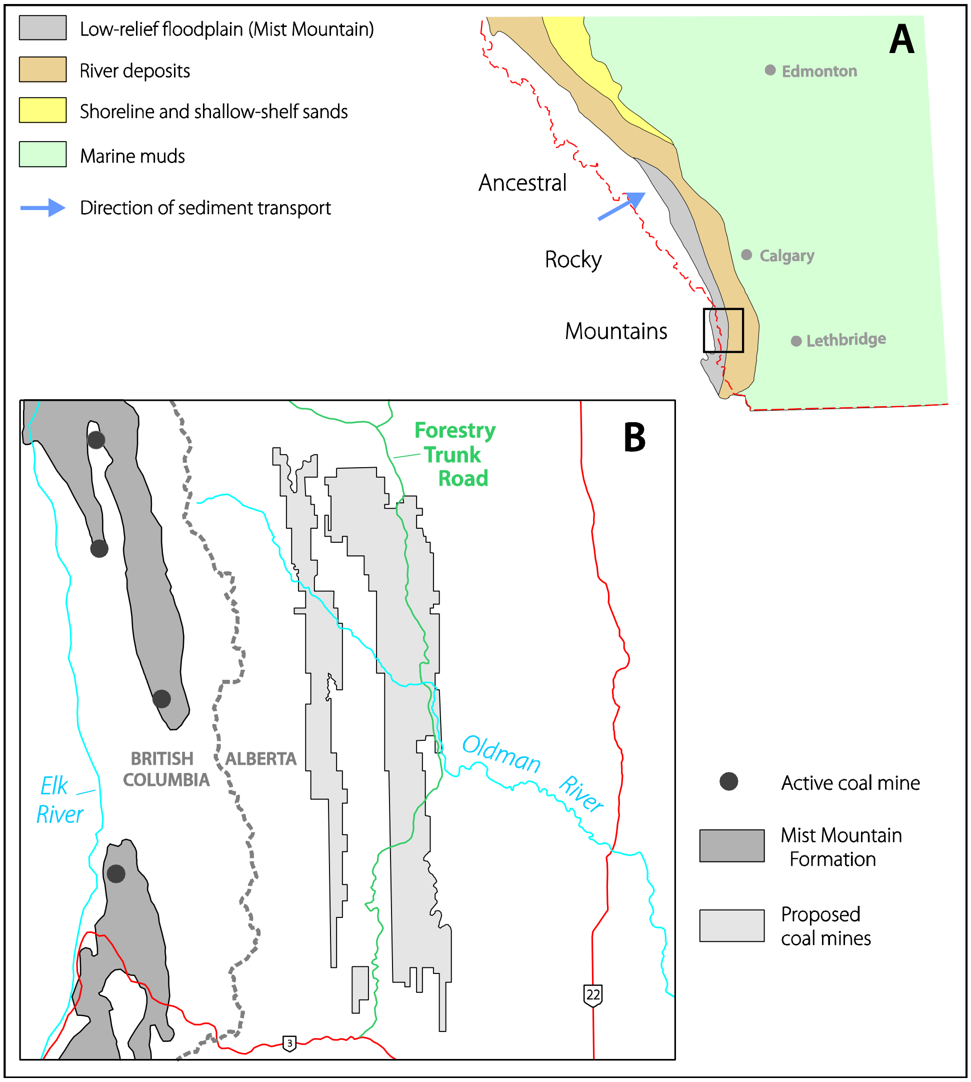

Figure 1. A. Map showing the types of sediments deposited during the time that the Mist Mountain coals were being formed, about 145 million years ago, in what was to become southern Alberta. **B.** Enlargement of the small square in map A, showing the active coal mines in the Elk River Valley, British Columbia and the proposed coal mining areas in Alberta's eastern slopes.

6. Laundering the coal

We have already discussed the inevitability of selenium leaching out of piles of waste rock. Severe though this problem is, it is not the worst that is encountered when strip-mining is practiced in selenium-bearing rock. That dubious honour goes to the process that produces what is called, with no sense of irony, *clean coal*.

The name is misleading. It would have you believe that a variety of coal has been engineered that is going to somehow chip in and do its bit to combat global warming, but such is not the case. All that '*clean coal*' means is that, to satisfy market demands, the coal has had a bath before it leaves the mine site.

It takes enormous quantities of water to cleanse tonnes of coal of its soil and extraneous rock. It is also treated to other processes, such as crushing, screening, gravity separation, and de-watering. Processing may also involve the use of chemicals, thereby escalating the toxicity of the waste water.

The waste waters are stored in pit lakes for what mining companies call "sufficient water residence time", the hope being that the selenium they contain will either settle out or be removed by biological means.

This is not going to happen, Lemly says. "Retention ponds, even when coupled with enhanced active treatment steps, have not been demonstrated to work, and will not work."

Besides the fact that no one so far has been able to render process waters chemically harmless, pit lakes are notorious for breaching. One such disaster occurred on October 31, 2013 at the Obed Mountain mine near Hinton, when some 670,000 cubic metres of highly contaminated process waters broke through the pit's retaining wall to surge across the landscape. The waste water was carried some 1,100 kilometres by the Athabasca River, and traces of the plume were found north of the Peace-Athabasca Delta at Rivière des Roches (about sixteen kilometres downstream of Lake Athabasca's out-flow) – indicating that the plume had reached and exited Lake Athabasca (Cooke et al., 2016)…see Figure 2.

The possibility of a similar outflow from Alberta's mines makes this a concern for our federal government, since such a flow would carry Alberta-produced selenium across the provincial border into Saskatchewan, to accumulate in Lake Diefenbaker (see Figure 3).

In Lemly's view, allowing the use of such ponds, without any contingency plan, is like "allowing a speeding car to proceed with no brakes."

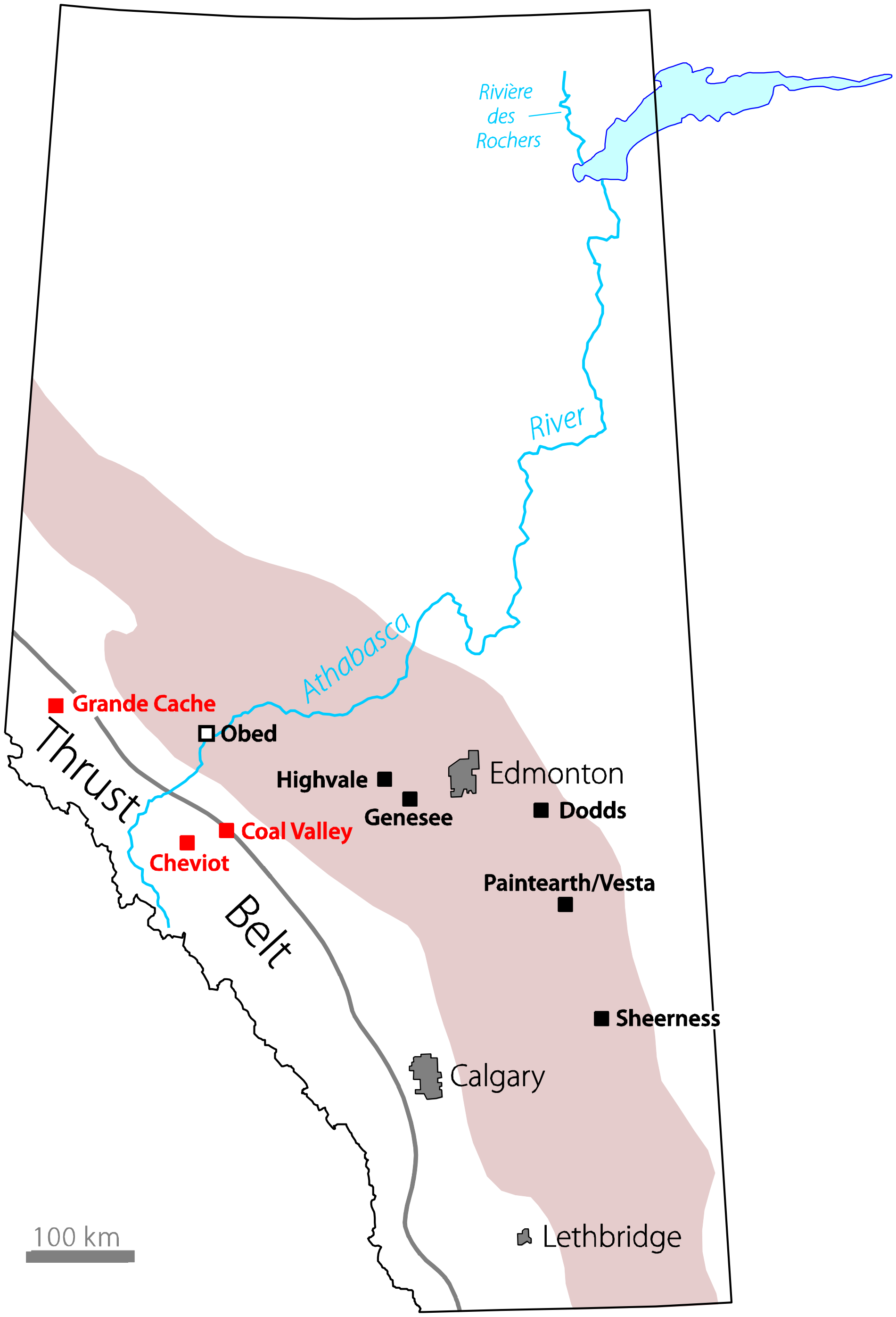

Figure 2. Map showing the active coal mines in Alberta at February 2020. Five mines in the coloured area produce coals mainly for electric power generation. Three mines in the thrust belt produce high-grade metallurgical coals. Also shown is the location of the abandoned Obed coal mine – site of "the largest coal slurry spill in North American history" (Cooke et al., 2016).

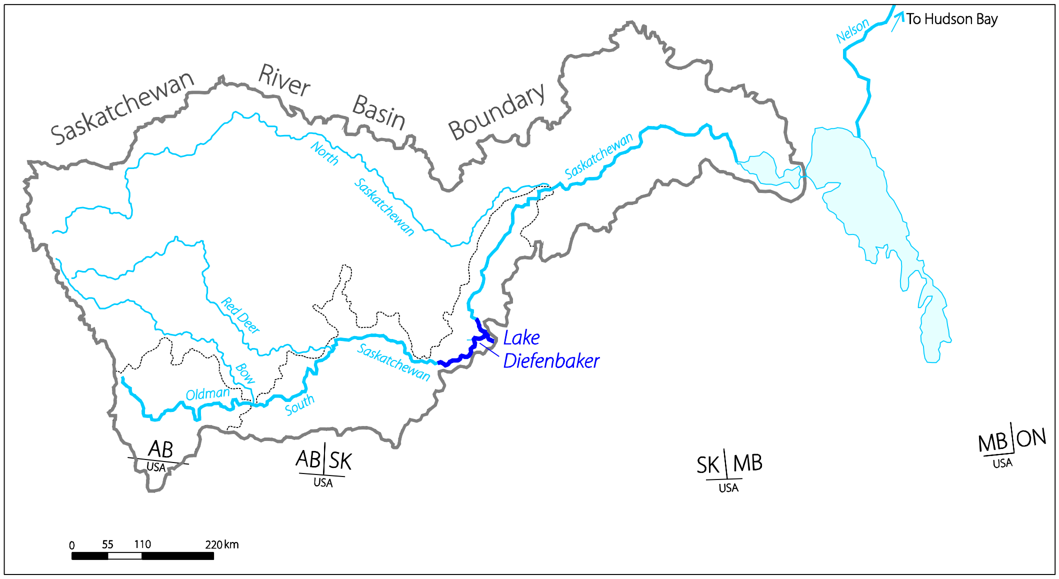

Figure 3. Map of the Saskatchewan River Basin (modified from Burke, 2011). A catastrophic release of coal cleaning waste comparable to the Obed disaster from mines in the headwaters of the Oldman River would send a plume of debris to Lake Diefenbaker, and possibly beyond.

PART TWO – More dire warnings

7. Human ingenuity *vs*. selenium

It is in the nature of developing businesses to be optimistic, to believe that new technology will have an answer to old problems. Or to think that one site is very different from another site, and so problems that have frustrated one operator can be easily put in their place by another. The latter is sometimes true, but, as we will show, it is not true in this case.

8. Lessons from the Elk River Valley

If there is one thing that the B.C. experience makes clear, it is that if you try to mine in the wrong kind of rock, your grief is going to be never-ending.

Teck Coal, a company mining in the Elk River Valley, knows this better than anyone. They knew they were polluting, and so in 2014 they introduced the $600-million Line Creek water treatment plant, designed to treat waste water by both biological and chemical means (Linnitt, 2020). It was promoted as a 'state of the art' solution to the selenium problem. And yet just six months after opening, they had to shut their plant down because it was killing the fish at a greater rate than before. It turned out that their 'state of the art' plant had converted the selenium into an even more toxic form.

The company has still not been able to find a solution, which is not surprising. The sentence that begins, "If we can put a man on the moon…" (meaning "we can surely lick this problem") does not seem to apply to selenium containment.

Part of the problem is magnitude. It is estimated that during the years that the Elk Valley mines have been in operation, their waste rock piles have grown to several billion tonnes. And the leachate from this is, of course, in addition to the amounts of selenium that have been washed off during coal processing.

Some further Lemly quotes are of interest:

"Available treatment measures to protect water quality from selenium in coal mining waste are ineffective, despite their elaborate technical design and high cost."

"There has been no demonstrated success for selenium removal on the scale needed to treat mountaintop open pit mine waste."

"To date, there has been no demonstrated effective mitigation measure, physical or chemical, for eliminating this pollution threat."

9. Dangers to the water supply

The dangers to towns located downstream from mines that rely on the river for their water needs are self-evident. However, experience has also shown that groundwater can be polluted, meaning that towns and individuals who get their water supply from water wells are no longer able to use that water for drinking.

The town of Sparwood had to shut down one of the three wells that supplied it with water from when that well was found to exceed Canadian Drinking Water Guidelines for selenium by a whopping 12%. Wells belonging to private landowners were also affected, and Teck Coal supplied these people with bottled water for drinking (Williams, 2019). (It is not known to this writer if any livestock were affected.)

10. Exporting pollution

One of the serious hazards of selenium pollution comes from its downstream transport to waters hundreds of kilometres away (see Figure 4). Selenium is an element. It doesn't biodegrade. It travels intact. And its strength intensifies when it enters a lake or still-water reservoir (Lemly, 1993).

Selenium loads from the Elk River Valley increased six-fold in Montana's Lake Koocanusa over twenty years: from 2,000 kilograms in 1992 to 13,000 kilograms in 2012. Just think of that. The Elk Valley exported 13 metric tonnes of selenium to the United States in one year…and the load may have gone up since then. (Up-to-date amounts have been requested from the U.S. but have so far not arrived.)

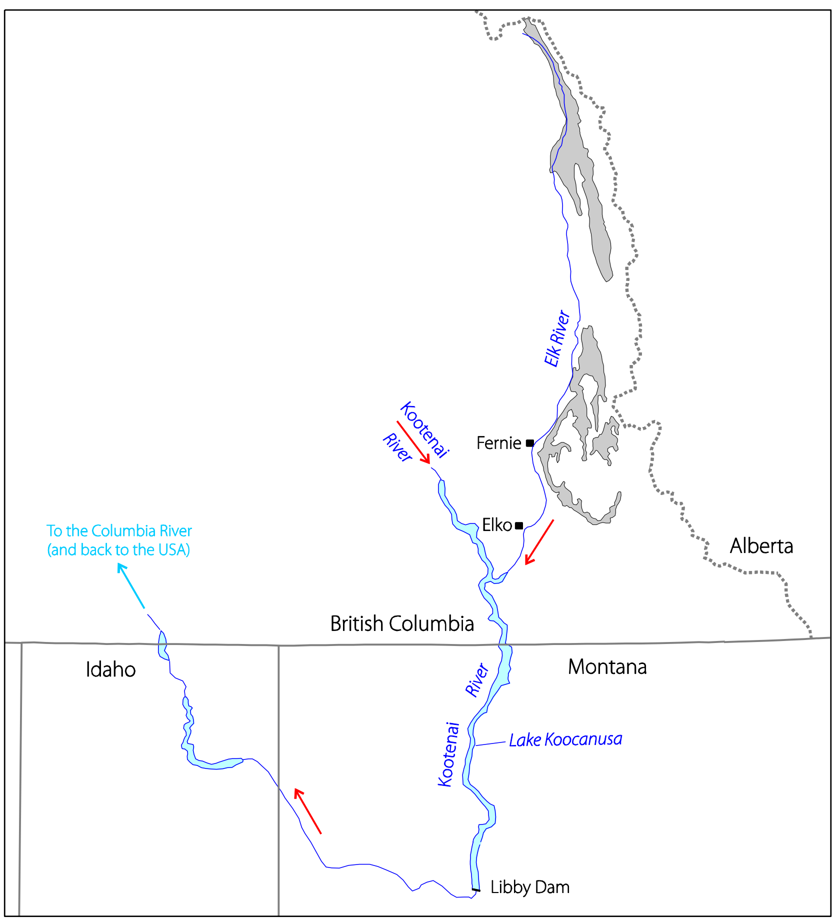

Figure 4. Map showing the coal-bearing Mist Mountain (light grey areas) in the Elk River Valley, British Columbia, and the route of selenium pollution to Lake Koocanusa. For the purpose of this report only transborder pollution into the USA was considered.

11. Implications for native species

Coal development in the Elk River Valley has been called "one of the biggest selenium contamination issues in the world," (Williams, 2019, quoting Dr. Erin Sexton, Senior Scientist, Flathead Lake Biological Station, University of Montana) – so it is not surprising that its effect on fish and water birds, although not completely known, has been dire. The numbers tell the tale. In B.C., at least 180,000 newly-hatched trout perish each year because of selenium poisoning.

The survival of western slope cutthroat trout, a threatened species, has been of particular concern. The cutthroats are highly sensitive to selenium and they – along with water birds, insects and other fish – have been shown to have higher than normal amounts of selenium.

Selenium has a strong ability to 'bioaccumulate' and 'biomagnify', which means that even very low amounts of the element can become increasingly toxic and more dangerous as they move up the food chain from one species to another. Human health may be impacted if selenium levels rise in the bodies of fish and birds commonly used for food.

The young of any species are most at risk. Downstream from the Elk Valley mines, the eggs of aquatic birds, including the spotted sandpiper, have shown reduced hatchability.

The Lemly report describes some extraordinary efforts that the province of Alberta has made to reverse its dwindling numbers of cutthroat trout. Substantial funds and staff hours have been spent to this end, and the trout have even been flown by helicopter to healthier habitats in an effort to save them, efforts that will have largely been wasted if we allow the inevitable increase in selenium that would come with allowing these mines to open. It should be mentioned that destruction of the habitats of any threatened species is strictly prohibited by both Canadian law and the Canada–U.S. Migratory Bird Treaty Act.

Fish suffer in more than one way: directly from the selenium and indirectly from other pollutants in the waste water, which include various salts, acid-forming materials, heavy metals, and trace elements. Calcite is often deposited in stream beds, in effect coating them with 'cement' and thus eliminating the loose gravel necessary for spawning. "There is no longer any plausible denial of the threat posed by the selenium released by coal mining" Lemly says.

12. The cost to our own south country

No one has more at stake in the decision about whether to allow strip mining on the Eastern Slopes than the people of southern Alberta, and particularly those living in the Oldman River Watershed.

They live in country that is beautiful – often ravishingly so – but it is also dry. Farmers here, if they do not have irrigation, often seed one year's crop through the previous year's stubble, to save every drop of precious rain and also to protect their soil from the dry winds that blow almost all the time.

People here are more aware than most that water is a resource that must be carefully husbanded, that there is not enough to squander. This is one of the reasons why so many of their municipalities have written the provincial government opposing mine development. If anything affects their available supply of water, there is no replacing it.

The future is worrisome enough, even without the present challenge. If climate change should reduce the flow of water in the Oldman – as has been predicted – or if growth in population in Lethbridge should increase that city's need for water, it may become necessary to change the way that water is presently allotted in the region. If the mines were to open, with their enormous need for water for coal processing, the situation could become untenable.

So far, we have been talking about water *quantity*. There is also the question of water *quality*. As we have seen, neither human ingenuity nor the outlay of vast amounts of money has been able to control the entry of selenium into B.C. waters…and the Oldman is not a B.C. river. In years when river flow is diminished, concentrations of selenium rise. If it were to rise above the Canadian Drinking Water Standard (no more than 0.05 parts per million), the 193,000 people in Lethbridge would have to look for another source for their drinking water. And where, in a dry land, would they find it? Perhaps it is time to remember that it was lack of water – drought, plus taking too much from the environment – that forced the ancient Mayan to abandon the great cities they had carved out of the drylands and jungles of Middle America.

If, in spite of the advice received from many sources, the Government of Alberta were to wish to go ahead with these mines, it would be absolutely essential to delay the signing of any permits for time to determine a mass balance for selenium in the Oldman watershed. This would tell us how much selenium was contributed, naturally, to the various sub-basins of the Oldman. Only then could effective limits be put on a contribution from coal mining. It would be irresponsible to proceed without this precaution, and I trust that our government would not want to answer to the electorate for such an omission.

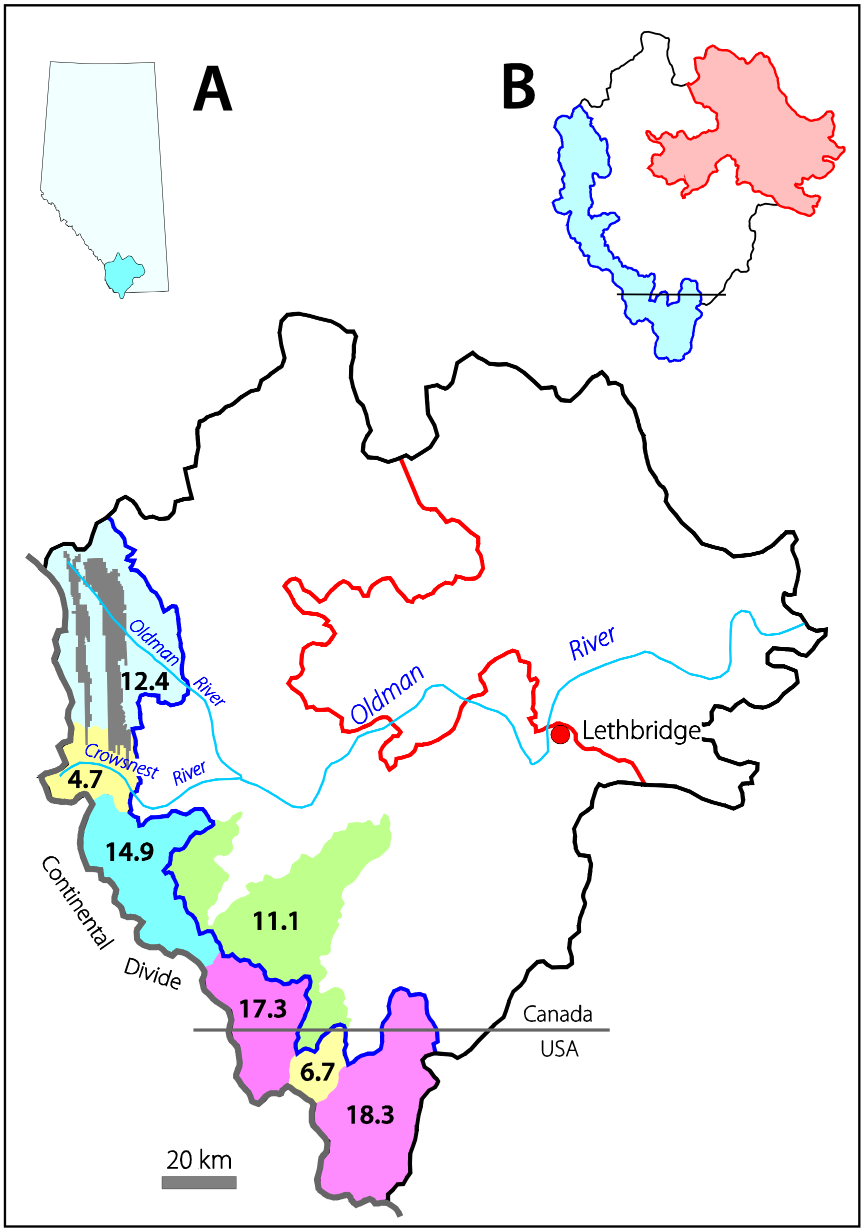

Figure 5. Map of the Oldman River Watershed. The map shows the percent contribution of the various sub-basins to the total streamflow (1971–2000). Simplified from the map of Kienzle and Mueller (2010). **A.** Relation to Alberta. **B.** The three main areas contributing to total basin flow. The area coloured blue supplies three quarters of the total flow in the basin. The white part effectively contributes the rest – because the contribution in the red area is extremely low. The two grey areas are the proposed mining sites.

13. The shrinking future of coal

It has been said that as long as the world needs steel, it is going to have to tolerate coal, and that was true once. But necessity is the mother of invention and with the world's current determination to phase out coal a number of new processes have been developed. The technology to accomplish that is here now…electric arc furnaces. They presently produce 24% of the world's steel, mainly from scrap steel. But with cheap hydroelectric power to generate hydrogen and a nearby iron ore deposit 'green steel' is imminent. Developments in Sweden are leading the way.

The International Energy Agency expects more than half the world's steel to be produced by electric arc furnaces by 2050. Coal passed its 'best before date' in 2020 (IEA, 2021). If that is true, it is quite possible that these mines, if allowed to open, would be closing again long before they were mined out. Buying into these mines at this point in time would be like going into the buggy whip business after Henry Ford had already begun to roll out Model A's on his assembly line. Albertans would be receiving very little in return for the risks they are assuming.

Summary

- Very large amounts of rock will have to be broken up and moved if this mining takes place: nearly six tonnes of rock for every tonne of coal produced.
- The rock in this formation contains pyrite. When the rock is broken up, the pyrite interacts with air and rain water to release selenium, which is flushed out to join the streams and rivers of the watershed. There is no way to prevent this happening, and tests show that it may be predicted to continue for a century or more after the mines have closed.
- The coal must be washed and processed before leaving the mine site. Not only is this a heavy demand on the waters of the region, but the waste water contains even more selenium than the leakage from rock piles. It must be stored in large holding ponds. According to the world's leading expert on selenium contamination, none of the processes that have been tried to remove selenium from waste water have worked.
- Waste water storage facilities are prone to rupture. When this happens, the contaminated waste water may travel hundreds of kilometres from the original site.
- We are able to predict some of the problems that mining would encounter in this locale because of mining that has taken place in the same rock formation on the B.C. side of the Rockies.
- In the B.C. mines, neither human ingenuity nor the expenditure of millions of dollars has been able to solve the selenium problem.
- Selenium pollution from the B.C. mines has travelled many kilometres from the mine site, across the international boundary and into Montana.
- Selenium poisoning causes gross deformities in fish, reduced hatchability in the eggs of birds, and nervous system and other damage in humans. The young of any species are the most at risk. In B.C., 180,000 newly-hatched trout perish each year because of selenium poisoning.
- Southern Alberta, which is dry country with limited water resources, is especially at risk should the opening of these mines affect the safety of the Oldman River.
- With steel production world-wide moving away from the use of coking coal, these mines may not be economic to operate for as long as anticipated, which would constitute poor recompense for the risks Albertan's are being asked to assume.

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Williams, Chloe (2019) From Canadian coal mines, toxic pollution knows no borders. *Yale Environment 360*, April 1, 2019.

NOTES ON SOURCES CONSULTED

Mist Mountain Formation

The Mist Mountain Formation (part of the Kootenay Group) spans a short time interval across the Late Jurassic – Early Cretaceous boundary, which is dated at about 145 million years. Mist Mountain rocks occur in southwest Alberta and adjacent southeast British Columbia and comprise non-marine sandstones, shales, and coal-bearing units, with some coals up to 18 m thick. The environment of deposition was a low-relief floodplain bordering a wide sea situated parallel to the ancestral Rocky Mountains (see Figure 1, page 4, compiled from Poulton et al., 1994 and Smith, 1994).

Gibson, D.W. (1985) Stratigraphy, sedimentology and depositional environments of the coal-bearing Jurassic-Cretaceous Kootenay Group, Alberta and British Columbia. Geological Survey of Canada, Bulletin 357.

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Smith, D.G. (1994) Paleogeographic evolution of the Western Canada Foreland Basin. In *Geological Atlas of the Western Canada Sedimentary Basin* (Grant Mossop and Irina Shetsen, Compilers), pp 277–296 [Map Figure 17.2]. Canadian Society of Petroleum Geologists and Alberta Research Council.

Coal mining in the Elk River Valley

In the Elk River Valley coal is mined by open-pit mining but the actual method is not as important as the fact that these and similar mining methods produce huge amounts of waste rock.

Lussier et al. (2003) described the waste in the Elk River Valley as mainly siltstone and mudstone, with coal from seams that were too thin or too poor to recover. The coal-to-waste ratio from five mines was 5.86, or almost six times the amount of coal produced (which was about 31 million tonnes in 2018, with more than 180 million tonnes of waste). At the rate at which coal has been produced over the years the total waste is of the order of several billion tonnes. The huge amount of waste rock is therefore the crux of the selenium story.

Lussier, C., V. Veiga and S. Baldwin (2003) The geochemistry of selenium associated with coal waste in the Elk River Valley, Canada. *Environmental Geology*, volume 44, 905–913.

Hendry, M. Jim, Ashis Biswas, Joseph Essilfie-Dughan, Ning Chen, Stephen J. Day and S. Lee Barbour (2015) Reservoirs of selenium in coal waste rock: Elk Valley, British Columbia, Canada. *Environmental Science and Technology*, volume 49 (issue 13), 8228–8236.

Pyrite and selenium

As long as pyrite remains in the rock, out of contact with air (oxygen), then it remains in a reducing environment and any trace elements in it remain there. Once pyrite is exposed to air (oxygen) in coal waste piles the process can not be reversed.

Hendry et al. (2015) measured the volume of water and its contained selenium draining from the base of a waste dump. From this they calculated that at least 20% of selenium-bearing sulphides (mainly pyrite) in the waste were oxidized and released their selenium over the past 30 years (the time the mine had been operating). This means that it takes 150 years for all the selenium to be removed from pyrite in a waste pile…rather longer than the time to mine out all the coal.

Hendry, M. Jim, Ashis Biswas, Joseph Essilfie-Dughan, Ning Chen, Stephen J. Day and S. Lee Barbour (2015) Reservoirs of selenium in coal waste rock: Elk Valley, British Columbia, Canada. *Environmental Science and Technology*, volume 49 (issue 13), 8228–8236.

Selenium – a global pollutant

Dennis Lemly is recognized as a world authority for his research on selenium pollution. In his recent review of aquatic selenium pollution as a global environmental safety issue he lists 30 locations worldwide in which selenium pollution has contaminated fish and wildlife populations (Lemly, 2004, Table 2). Of this sample, seven are related to coal mining waste or coal combustion waste, including British Columbia (coal mining waste). He notes that: "Once selenium contamination begins, a cascade of bioaccumulation events is set in motion which makes meaningful intervention nearly impossible." He also lists values for selenium in a variety of materials (Lemly, 2004, Table 1). Some of the more pertinent for this report are given below. Note particularly the contrast between selenium in solid materials (coal and coal waste) and in water and leachates (especially the leachate from coal cleaning solid waste) – when coal is burned, selenium is further concentrated in fly ash.

SELENIUM IN MATERIALS RELATED TO THE COAL INDUSTRY

Materials or Waste	Selenium
Solids	**(µg/g)**
Coal	0.4–24
Coal cleaning solid waste	2.3–3.1
Coal burner ash (bottom ash)	7.7
Liquids	**(µg/L)**
Surface water (average)	0.2
Coal storage pile leachate	1–30
Coal cleaning process water	15–63
Coal cleaning solid waste leachate	2–570
Fly ash leachate	40–610

For solids: µg/g = microgram per gram
For liquids: µg/L = microgram per litre.

Lemly, A. Dennis (2004) Aquatic selenium pollution is a global environmental safety issue. *Ecotoxicology and Environmental Safety*, volume 59, 44–56.

Following the path of selenium

Selenium is an element that is commonly present only in small amounts and in many disguises. It may travel through the environment as a single atom, or combined into molecules with other elements, including organic molecules. It is necessary for proper biological functioning but may also be toxic.

Equally important to the amount of selenium leaking from a waste pile is the fact that the selenium is in water and can therefore enter the food chain. A recent critical review by Etteieb et al. (2020) of selenium as related to the mining industry notes that excessive levels of selenium "may induce toxicity in humans as selenosis, in grazing animals as alkali disease and in aquatic organisms as larval and developmental deformities and mortality."

Etteieb, Selma, Sara Magdouli, Mehdi Zolfaghari and SatinderKaur Brar (2020) Monitoring and analysis of selenium as an emerging contaminant in mining industry: A critical review. *Science of The Total Environment*, volume 698, 1 January 2020. Article 134339.

Selenium and the food chain

Food chain refers to the feeding relations between organisms in a particular environment – each organism depends on the next lowest member of the chain for its food (*The Hutchinson Encyclopedia of Science*). For the purpose of this report, the food chain is aquatic plants, aquatic insects, fish, and water birds. Selenium reaching rivers can enter the food chain because it is in a form in which it can be

ingested. Thus we can measure selenium in aquatic insects and higher life forms that feed on them to see how much has accumulated and any effects that may have produced.

Selenium pollution in the Elk River Valley

For a definitive evaluation of selenium pollution in the Elk River Valley we must turn again to the research of Dennis Lemly. In an early paper (Lemly, 1993) he noted that any content of selenium in water that is greater than two parts per billion (2 ppb) "should be considered hazardous to the health and long-term survival of fish and wildlife populations due to the high potential for food-chain bioaccumulation, dietary toxicity, and reproductive effects." Twenty years later, as an expert witness, he reviewed a report prepared by Environment Canada concerning their toxicology tests on westslope cutthroat trout in the Elk River and Fording River (Lemly, 2014). He starts his report with the statement "Selenium pollution in the Fording and Elk Rivers has been a growing environmental issue for many years." So his early limits have thus been known throughout the many years in which selenium pollution has been observed in the Elk River Valley, apparently to little effect.

With respect to the food chain, selenium is already enriched in the initial source (pyrite) and is further enriched as it moves from the water, through insects to fish and water birds. In other words, as you move up the food chain the effects become more apparent and devastating.

Lemly, A. Dennis (1993) Guidelines for evaluating selenium data from aquatic monitoring and assessment studies. *Environmental Monitoring and Assessment*, volume 28, 83–100.

Lemly, A. Dennis (2014) Review of Environment Canada's Teck Coal Environmental Assessment and Evaluation of Selenium Toxicology Tests on Westslope Cutthroat Trout in the Elk and Fording Rivers in Southeast British Columbia. Expert Report, 148 pages.

Selenium and aquatic insects

Three investigations on selenium in aquatic insects show that for the same insect group, those from streams affected by coal mining had enhanced contents of selenium compared to populations in reference streams where there was no coal mining. Study areas included the Elk River Valley and streams in west-central Alberta.

Kuchapski, Kathryn A. and Joseph B. Rasmussen (2015) Surface coal mining influences on macroinvertebrate assemblages in streams of the Canadian Rocky Mountains. *Environmental Toxicology and Chemistry*, volume 34 (issue 9), 2138–2148.

Luek, Andreas and Joseph B. Rasmussen (2017) Chemical, physical, and biological factors shape littoral invertebrate community structure in coal-mining end-pit lakes. *Environmental Management*, volume 59 (issue 4), 652–664.

Wayland, Mark and Robert Crosley (2006) Selenium and other trace elements in aquatic insects in coal mine-affected streams in the Rocky Mountains of Alberta, Canada. *Archives of Environment Contaminant Toxicology*, volume 50 (issue 4), 511–522.

Selenium and fish

Coal mining companies have been aware of high selenium in fish (and other wildlife) in the Elk River Valley through a series of selenium status reports prepared on their behalf by Golder Associates Ltd. (Selenium Status Report, 2003, 2005/2006, 2007). The reports show clear evidence of toxic effects on fish. More recently, laboratory studies (Rudolph et al., 2008) and field studies (Orr et al., 2012) show that where selenium contents in rivers and streams are high, westslope cutthroat trout exhibit toxic effects, including spinal deformities, missing gill covers, edema in young fish and concentration of selenium in eggs, resulting in mortality of alevin (newly born trout still carrying the yolk sac). It was clear that by 2014 the Elk River watershed was at a tipping point. By the fall of 2019, the dire prediction of five years earlier had come to pass – there was a 93% drop in the adult population of the westslope cutthroat trout (Linnitt, 2020).

Pit lakes are a common reclamation strategy for open pit mines and Miller et al. (2013) investigated selenium in stocked fish in pit lakes in Alberta, some of which were associated with mines earlier

producing metallurgical coal. They concluded that the high selenium exposure in these coal pits "indicates that under the current mining and reclamation strategy, these lakes are not suitable for management as recreational "put and take" fisheries." So putting fish in high-selenium pit lakes is bad for the fish and those who eat them.

Linnitt, Carol (2020) Unique B.C. trout population suffers 93 per cent crash downstream of Teck's Elk Valley coal mines. *The Narwhal*, April 16, 2020.

Miller, L.L., J.B. Rasmussen, V.P. Palace, G. Sterling and A. Hontela (2013) Selenium bioaccumulation in stocked fish as an indicator of fishery potential in pit lakes on reclaimed coal mines in Alberta, Canada. *Environmental Management*, volume 52 (issue 1), 72–84.

Orr, P.L., C.I.E. Wiramanaden, M.D. Paine, W. Franklin and C. Fraser (2012) Food chain model based on field data to predict westslope cutthroat trout (Oncorhynchus clarki lewisi) ovary selenium concentrations from water selenium concentrations in the Elk Valley, British Columbia. *Environmental Toxicology and Chemistry*, volume 31 (issue 3), 672–680.

Rudolph, Barri-Lynn, Iisak Andreller and Christopher J. Kennedy (2008) Reproductive success, early life stage development, and survival of westslope cutthroat trout (Oncorhynchus clarki lewisi) exposed to elevated selenium in an area of active coal mining. *Environmental Science and Technology*, volume 42 (issue 8), 3109–3114.

Selenium Status Report 2003. Prepared by Golder Associates Ltd. for the Elk Valley Mines Environmental Management Committee, 42 pages.

Selenium Status Report 2005/2006. Prepared by Golder Associates Ltd. for the Elk Valley Selenium Task Force (EVSTF). Final Draft: May 2007, 67 pages.

Selenium Status Report 2007. Prepared by Golder Associates Ltd. for the Elk Valley Selenium Task Force (EVSTF), December 2008, 47 pages.

Selenium and water birds

High selenium amounts have moved up the food chain to water birds. The American Dipper is a small slate gray bird found in the Rocky Mountain natural region. It lives near clear, fast-flowing streams and is a recognized indicator of stream quality. Selenium is usually determined in eggs (the clutch is commonly 3-6 and one egg is not missed), feathers, and feces. In both the Elk River Basin (Morrissey et al., 2005, 2012) and northern Alberta (Wayland et al., 2006, 2007) all are significantly contaminated compared to dippers in streams where there are no coal mines. The American Dipper is classified as Secure in Alberta (*The Atlas of Breeding Birds of Alberta: A second look*, 2007, page 410) but that classification should probably be reconsidered. Selenium has also been measured in eggs of the Spotted Sandpiper, a wading bird found close to many lakes and streams (Harding et al., 2005) and in Harlequin Ducks.

Harding, Lee E., Mark Graham and Dale Paton (2005) Accumulation of selenium and lack of severe effects on productivity of American Dippers (Cinclus mexicanus) and Spotted Sandpipers (Actitis macularia). *Archives of Environmental Contaminant Toxicology*, volume 48 (issue 3), 414–423.

Morrissey, Christy A., Leah I. Bendell-Young and John E. Elliott (2005) Assessing trace-metal exposure to American Dippers in mountain streams of southwestern British Columbia, Canada. *Environmental Toxicology and Chemistry*, volume 24 (issue 4), 836–845.

Morrissey, Christy A., Ingrid L. Pollet, Steve J. Ormerod and John E. Elliott (2012) American dippers indicate contaminant biotransport by Pacific salmon. *Environmental Science and Technology*, volume 46 (issue 2), 1153–1162.

The Atlas of Breeding Birds of Alberta: A second look. (2007) The Federation of Alberta Naturalists.

Wayland, Mark, Jeff Kneteman and Robert Crosley (2006) The American Dipper as a bioindicator of selenium contamination in a coal mine-affected stream in west-central Alberta, Canada. *Environmental Monitoring and Assessment*, volume 123, 285–298.

Wayland, Mark, Richard Casey and Eric Woodsworth (2007) A dietary assessment of selenium risk to aquatic birds on a coal mine affected stream in Alberta, Canada. *Human and Ecological Risk Assessment*, volume 13 (issue 4), 823–842.

Selenium and bighorn sheep

Flueck et al. (2012) reviewed the implications of selenium deficiency on wild herbivores, including the work of Samson et al. (1989) on selenium in Rocky Mountain bighorn sheep and mountain goats in Alberta. Their literature review of 241 references suggested that "subclinical nutritional Se deficiency may be common, especially at alpine locations." Valley bottoms are the optimum places from a "mineral nutritional view" and when access is no longer possible "animals are forced to live in a nutritionally marginal habitat." Kneteman (2013) suggests that the "safe operating interval" for

selenium in bighorn sheep is 0.06-0.30 μg/g. Most bighorn sheep fall within this range except where they are from areas impacted by coal mines, where selenium amounts may be up to nearly 0.6 μg/g (Kneteman, 2013, Figure 3.3). The route by which the sheep ingest selenium is not clear (through coal dust deposited on grass or drinking high-selenium water, for example).

Flueck, W.T., J.M. Smith-Flueck, J. Mionczynski and B.J. Mincher (2012) The implications of selenium deficiency for wild herbivore conservation: a review. *European Journal of Wildlife Research*, volume 58, 761–780.

Kneteman, Jeffery Grant (2016) Resilient Space: Bighorn sheep (*Ovis canadensis*) ecological resilience in the northern Rocky Mountains. Master of Science in Ecology, Department of Biological Sciences, University of Alberta.

Samson, Judith, Jon T. Jorgenson and W.D. Wishart (1989) Glutathione peroxidase activity and selenium levels in Rocky Mountain bighorn sheep and mountain goats. *Canadian Journal of Zoology*, volume 67, issue 10, 2493–2496.

Selenium and groundwater pollution

In the Elk River Valley there are two cases of groundwater pollution by selenium originating from coal mining operations – both from investigations by journalists. Nicole Obre reported that Well No. 3 (out of three wells) that supply the town of Sparwood with drinking water had been shut down because selenium values exceeded Canadian Drinking Water Guidelines by 12% (Obre, 2014). Later investigations indicated that the water quality data from the shut down well "suggests that there is surface water infiltration into the well water (groundwater) during seasonal low flow conditions, when selenium concentration in the rivers are at their most elevated level." Chloe Williams (2019) reports that the company (Teck) has been "supplying bottled water to landowners whose private wells contain selenium levels exceeding British Columbia's standard" – the date when this started or the circumstances are not given. Clearly, selenium from coal mining operations can pollute groundwater in at least two quite different scenarios.

Obre, Nicole (2014) Sparwood well shut down due to high selenium levels. *The Free Press*, March 28, 2014, 10:00 a.m.

Williams, Chloe (2019) From Canadian coal mines, toxic pollution knows no borders. *Yale Environment 360*, April 1, 2019.

Selenium crosses the Canada-US border

Selenium entering the Elk River travels downstream to where it joins the Kootenai River – more precisely, Lake Koocanusa, which was created when the Libby Dam in Montana was constructed on the Kootenai [Contrary to initial impressions, the name Koocanusa is not from an indigenous source but is derived from <u>Koo</u>tenai, <u>Can</u>ada, and <u>USA</u>]. Beyond the dam the Kootenai flows back into Canada. The red arrows in Figure 4 (page 9) show these flow directions. Selenium pollution from the coal mines in the Elk Valley has thus become an international problem.

The US Geological Survey has been working with numerous agencies and has compiled data showing that the annual selenium loads entering Lake Koocanusa from the Elk and Fording rivers in Canada "have increased from 2,000 kg in 1992 to over 13,000 kg in 2012, representing more than a 5-fold increase over 20 years." Put simply, in 2012 Canada was exporting 13 metric tonnes of selenium to the United States from our coal mine operations in the Elk River Valley. (the current amount has been requested from the USGS).

Assessing the impacts of mining in the Transboundary Flathead and Kootenai River systems. U.S. Geological Survey, Active Status report.

Lifetime selenium footprint of the Elk River Valley

Hendry et al. (2015) have provided enough data to estimate the lifetime selenium footprint of coal mining in the Elk River Valley. The key data at 2010 are listed below.

Cumulative volume of waste rock stored in dumps estimated at 4.7 billion cubic metres (4.7×10^9 m^3)
Volume of waste rock in the Line Creek dump 2×10^8 m^3
Average annual flux of selenium from the Line Creek dump 710 kg
Total selenium released from the Line Creek dump over the 30 year life of the dump 2.1×10^4 kg
At least 20% of selenium oxidized and released over 30 years at the Line Creek dump
This means that the total selenium released at the Line Creek dump over the lifetime of the dump is

10.5×10^4 kg and over the lifetime of the Elk River Valley 246.8×10^4 kg or about 2470 metric tonnes.

Hendry, M. Jim, Ashis Biswas, Joseph Essilfie-Dughan, Ning Chen, Stephen J. Day and S. Lee Barbour (2015) Reservoirs of selenium in coal waste rock: Elk Valley, British Columbia, Canada. *Environmental Science and Technology*, volume 49 (issue 13), 8228–8236.

The Obed event

The products of coal cleaning are particularly high in selenium (see table, page 17). This means that extra precautions must be exercised in how they are treated. On 31 October, 2013 there was a catastrophic release of approximately 670,000 cubic metres of coal process water due to failure of the wall of a post-processing settling pond at the Obed Mountain mine near Hinton (Figure 2, page 6). The released plume travelled approximately 1100 km downstream, along the Athabasca River to the Peace-Athabasca Delta (Cooke et al., 2016). Elevated contents of selenium, arsenic, mercury, lead, and zinc were reported in the plume. This study confirms two important things. First, impounding liquids from coal mining operations is no guarantee of security, and second, the association of this group of elements is characteristic of pyrite oxidation. It emphasizes that concentrating only on selenium does not explain all toxic elements associated with coal mining.

Cooke, Colin A., Colin Schwindt, Martin Davies, William F. Donahue and Ekram Azim (2016) Initial environmental impacts of the Obed Mountain coal mine process water spill into the Athabasca River (Alberta, Canada). *Science of the Total Environment*, volume 557–558, 502–509.

Oldman River Watershed

Two coal mining proposals are currently under consideration, both in the Oldman River Watershed. Because Grassy Mountain is not in the remit of the Coal Policy Committee it is dealt with separately.

Figure 5 (page 12) shows the sub-basin that contains the headwaters of the Oldman River (based on a map by Kienzle and Mueller, 2010) and the location of proposed coal mines. Map A shows the position of the Oldman River Watershed in relation to Alberta. Map B summarizes the contribution of each part to the total flow in the basin. The area coloured blue supplies three quarters of the total flow in the basin. The white part effectively contributes the rest – because the contribution in the red area is extremely low.

Note the position of Lethbridge, just at the red line. This means that the water intake for the city is downstream of effectively the entire flow in the basin. With certain assumptions, we can use this fact to calculate the maximum amount of selenium that can be put into the headwaters of the Oldman River (12.4% of the flow at Lethbridge) without exceeding the Canadian Drinking Water limit (0.05 mg/L, which is 50 μg/L) at Lethbridge. The assumptions are (1) that waterborne selenium concentrations of 2 μg/L or greater "should be considered hazardous to the health and long-term survival of fish and wildlife populations" (Lemly, 1993) and (2) that there is no contribution of selenium by any sub-basin, including the Oldman headwaters.

To avoid exceeding the selenium drinking water limit at Lethbridge the maximum selenium contribution from coal mining is $(50 \times 12.4)/100$ or 6.2 μg/L. This amount is already over the 2 μg/L threshold for protecting fish and aquatic life but we need to heed the conclusion of Erin K. Sexton, when she testified to the US Congress and stated (with respect to pollution on the Elk River) "contamination is over 100 times the threshold for protecting fish and aquatic life" (Sexton, 2020). So, based on the history of coal development in the Elk River Valley, selenium from coal mines will be a major contaminant, with severe consequences for drinking water in the Oldman River Watershed.

It is critical to determine a mass balance for selenium in the Oldman River Watershed so as to identify the selenium contributions from each sub-basins. The assumption of 'zero' selenium in all sub-basins is highly unlikely, based on research in other basins – but the more a selenium mass balance exceeds 'zero' the more important the decision to deny coal mining.

A catastrophic flow like that at Obed would send a plume of waste material as far as Lake Diefenbaker (Figure 3, page 7).

Burke, Amanda (2011) Drainage Basins of the South Saskatchewan and Saskatchewan Rivers. Map SSRWSI.

Kienzle, Stefan W. and Mark S. Mueller (2010) Map. Oldman River Watershed. Percent Contribution of Sub-watersheds to Total streamflow (1971-2000). Alberta Innovates, Energy and Environment Solutions.

Lemly, A. Dennis (1993) Guidelines for evaluating selenium data from aquatic monitoring and assessment studies. *Environmental Monitoring and Assessment*, volume 28, 83–100.

Sexton, Erin K. (2020) Typed document of testament before U.S. Congress, 2020-02-06. Downloaded from the web.

APPENDIX A – GRASSY MOUNTAIN

Although not part of the remit of the Coal Policy Committee, the proposed coal mine at Grassy Mountain, now no longer an issue, is in the Oldman River Watershed and so of concern for potential selenium contamination. The mine is in the sub-basin that includes the headwaters of the Crowsnest River – the pale yellow area in Figure 5 (page 12) that contributes 4.7% of the flow at Lethbridge. Figure 6 shows the proposed mine permit boundary and the land recently opened for coal development.

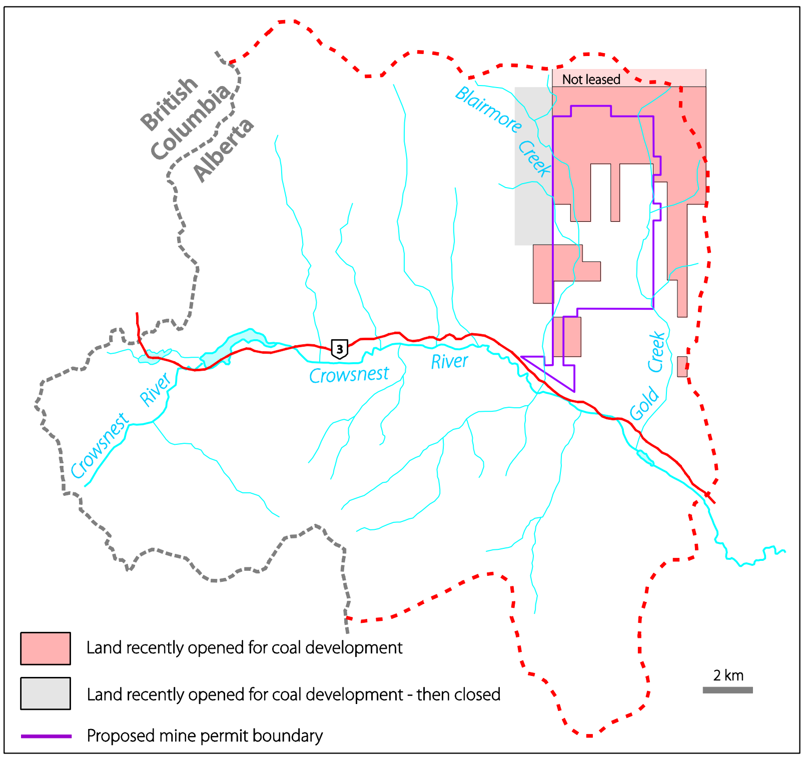

Figure 6. Map showing the proposed coal mine development at Grassy Mountain.

The coal that was to be mined at Grassy Mountain is in the Mist Mountain Formation which means that all the problems of selenium pollution that have been described for the Elk River Valley would also have applied to Grassy Mountain. The coal mining company has summarized their environmental impact assessment (Riversdale Resources Limited, 2014) which was totally inadequate when contrasted with the review of the problem by Lemly (2019). His review is attached to this report as a separate file.

REFERENCES

Riversdale Resources Limited (2014) Grassy Mountain Coal Project Environmental Impact Assessment: Project Summary Table [File 14-00201-01] 4 pages.

Lemly, A. Dennis (2019) Environmental hazard assessment of Benga Mining's proposed Grassy Mountain Coal Project. *Environmental Science and Policy*, volume 96, 105-113.

APPENDIX B – SOCIAL AND ECONOMIC ASPECTS

There are social and economic aspects to coal development that are not strictly part of a geological perspective but which may be of interest to the Coal Policy Committee. Below is a short description of two of the most relevant.

International Energy Agency

The International Energy Agency (IEA) recently released a report with the attention-getting title *Net Zero by 2050: A roadmap for the global energy sector*. Basically, production of solid fuels (coal) and fluid fuels (oil and gas) must be severely reduced if net zero emissions (NZE) of greenhouse gases are to be achieved by 2050. The IEA notes that achieving net-zero emissions by 2050 is a monumental task. Among their global milestones the ones for coal are as follows (IEA, Figure 4.1).

By 2021 – no new coal plants to be approved for development and no new coal mines or mine extensions to be approved without carbon dioxide reduction implemented (IEA so-called 'unabated coal').

By 2030 – phase-out of coal in advanced economies unless carbon dioxide reduction implemented (IEA so-called 'unabated coal').

By 2035 – overall net-zero emissions for electricity in advanced economies.

By 2040 – net-zero emissions for electricity globally; phase-out of all coal and oil power plants without carbon dioxide reduction implemented.

By 2050 – almost 70% of electricity generation globally from solar and wind.

For Canada, this would mean that effective immediately the only coal production would be from existing active mines and that all coal use would mean NZE within the present decade. Five years later, all electricity generation in Canada would be NZE. And thirty years from now almost 70% of the electricity generated in Canada would be from solar or wind. Certainly very ambitious guidelines – but ones that allow generation of jobs in advanced technologies and a reduction in global premature deaths and air pollutant emissions in advanced economies as well as emerging market and developing economies (IEA, Figure 4.12).

IEA (2021) *Net Zero by 2050: A roadmap for the global energy sector*. Directorate of Sustainability, Technology and Outlooks, International Energy Agency, Paris, France.

Steel and electric arc furnaces

There are basically two ways to convert iron ore into steel. The main process is the basic oxygen furnace, which requires metallurgical coal. The second process is using an electric arc furnace which does not require coal – it handles scrap steel and produces specialty steels. The IEA indicates that the share of steel production using electric arc furnaces must increase from 24% in 2020, to 37% in 2030 and reach 53% by 2050 (IEA, Table 2.5). Efforts to achieve this have already started in northern Sweden, where SSAB, a steelmaker, is "poised to deliver its first consignment of "eco-steel" from a hydrogen-fuelled pilot plant in Lulea" (*The Economist*, 2021). Volvo, an industrial-vehicle firm these days, will use the steel to build trucks. The key to this endeavour is cheap, 'green' hydropower (to produce hydrogen) and proximity to iron ore.

IEA (2021) *Net Zero by 2050: A roadmap for the global energy sector*. Directorate of Sustainability, Technology and Outlooks, International Energy Agency, Paris, France.

The Economist (2021) Green steel: Plentiful renewable energy is opening up a new industrial frontier. May 15th, pages 44–45.

ACKNOWLEDGEMENTS

I thank Dr. Bill Gunter, a colleague from my days at the Alberta Research Council, who reviewed this report and provided many valuable comments. Many thanks also are due to my partner, Merna Summers, who took my technically-oriented text and made it more readable.